

11.6.1.3 DESIGN GUIDELINES FOR INTEGRAL ABUTMENTS

Integral abutments, where appropriate, should be considered for most bridge projects in order to eliminate joints and bearings thereby simplifying construction and reducing maintenance problems. Integral abutments are defined as those abutments that are rigidly attached to both the superstructure and the supporting piles so that all thermal movements and girder end rotations are transferred from the superstructure through the abutment to the piles.

Design Limitations for the Use of Integral Abutments

Length: The total bridge length shall not exceed the following limits unless a more in-depth analysis is made.
Concrete Structures – 650 feet
Steel Structures – 350 feet

Skew: For bridge skews of 25 degrees or less, no skew effects need to be considered. For skews greater than 25 degrees the forces tending to rotate the structure shall be accounted for in the design.

Foundations: Abutments shall be supported on a single row of steel H-piles, steel smooth hollow pipe pile or steel-encased concrete piles utilizing smooth steel tubes. Piles should be embedded into the abutment concrete at least 2 feet. The preferred orientation of the piles is for bending about the strong axis. On skewed bridges the pile flanges should remain parallel with the abutment.

Abutment Thickness: The minimum thickness of the abutment wall should be 3 feet in order to provide enough width to encase the piles and girders.

Wing Walls: The wing walls should be cantilevered off of the abutments and shall be constructed parallel with the girders in order to minimize the soil pressure against the wings.

Pile Design Procedures

The number of piles in the abutment shall be based on the vertical load requirements. The total dead load reaction of the structure at the abutment shall be distributed to all piles equally. The live load reactions at each pile shall be determined by assuming the piles in the abutment act as a group:

$$R = \frac{P}{N} + \frac{Pex}{I}$$

where: R = single pile live load reaction (KIPS)
P = total live load reaction at the abutment, without impact (KIPS)
N = number of piles in the abutment
e = the eccentricity of the total live load relative to the center of the pile group (FT)
x = the distance from a given pile to the center of the pile group (FT)
I = the moment of inertia of the pile group (FT²)

For vertical loads piles shall be designed in accordance with Article 10.7 of the AASHTO LRFD Bridge Design Specifications for Strength I.

Lateral loads on the piles may need to be considered on bridges skewed more than 25° when required to resist the soil pressure forces tending to rotate the structure.

Piles must be ductile enough to accommodate both thermal movements and dead load and live load rotations of the superstructure. The ductility of the piles may be checked using the following equations:

For Steel H-pile:

$$2 \left[\frac{\Delta}{L} - \frac{M_p L}{6EI} \right] + \theta_w \leq \frac{3C_i M_p L}{4EI} \quad C_i = \frac{19}{6} - 5.68 \sqrt{\frac{f_y}{E}} \frac{b_f}{2t_f}, \quad 0 < C_i < 1.0$$

For hollow and concrete-filled pipe piles:

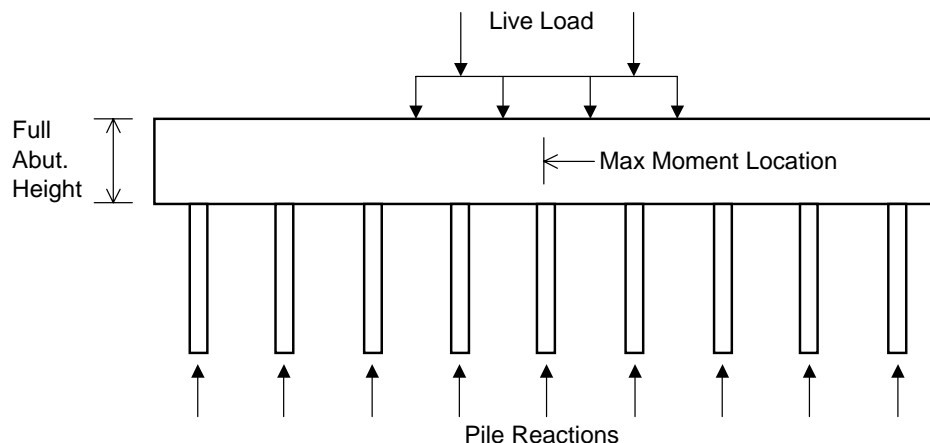
$$2\left[\frac{\Delta}{L} - \frac{M_p L}{6EI}\right] + \theta_w \leq \frac{C_i M_p L}{2.08EI} \quad C_i = 3.5 - 1.25\sqrt{\frac{f_y}{E}} \frac{D}{t}, \quad 0 < C_i < 1.0$$

- where:
- Δ = one half the factored thermal movement range at the abutment (IN)
 - L = twice the length from the bottom of the abutment to the first point of zero moment in the pile determined taking into account the effect of the soil on pile behavior and assuming a lateral deflection of Δ (IN)
 - M_p = plastic moment of the H-pile about the axis of bending or the plastic moment of the steel pipe pile without considering the concrete filling (KIP-IN)
 - E = modulus of elasticity of the steel (KSI)
 - I = H-pile moment of inertia about axis of bending, the moment of inertia of the hollow pipe, or moment of inertia of the concrete-filled pipe considering both the concrete and steel (IN⁴)
 - θ_w = maximum range of the factored angle of rotation of the superstructure at the abutment calculated assuming the structure is simply supported on the abutment (continuity of the superstructure over piers may be considered on multi-span bridges). This rotation is the sum of the rotations due to live loads plus all dead loads applied after making the rigid connection between the superstructure and the abutment assuming the loads are equally distributed to all girders (RAD)
 - C_i = a ductility reduction factor for piles
 - b_f = width of H-pile flange (IN)
 - t_f = thickness of H-pile flange (IN)
 - D = outer diameter of pipe pile (IN)
 - t = thickness of pipe pile (IN)

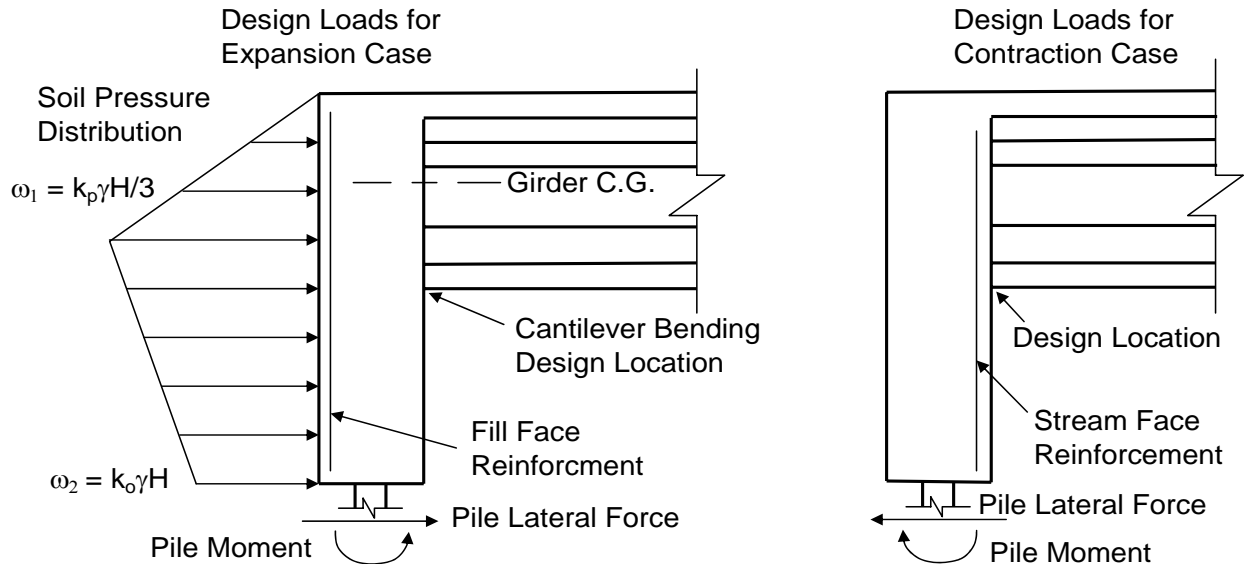
Abutment Backwall Design Procedures

The total height of the abutment shall be as short as practical with a minimum of 3 feet below the fill slope and 2 feet clear between the bottom of the girders and the fill slope. The abutment shall be designed for both Strength I and Service I using the following cases:

- Bending of the abutment acting as a horizontal pile cap for vertical dead loads and live loads assuming that all piles are loaded equally. The maximum positive moment (bottom steel) will occur approximately in the center of the abutment when the live load reactions are concentrated near the center; one, two, or possibly more lanes should be checked for positive moment. The maximum negative moment will occur approximately in the center of the abutment when two lanes are placed at the outside edges of the structure, two lanes will govern on abutments up to 80' wide. For dead loads only the pile cap section of the abutment shall be considered effective and for live loads the full abutment (both pile cap and end diaphragm) may be considered effective.



- Bending of the abutment acting as a vertical cantilever below the beam seat elevation to resist soil pressures and lateral pile forces and moments for thermal expansion, and the lateral pile forces and moments only for thermal contraction.



- Bending of the abutment acting as a continuous beam spanning between the girders under a soil pressure load. The full section of abutment (both pile cap and end diaphragm) may be used.

For all design elements the soil pressure distribution may be assumed as the passive pressure for the top third of the abutment with the pressure varying linearly down to the at-rest pressure at the base of the abutment (strength I load factor for soil pressure of 1.00, Article C10.5.5). This distribution is appropriate for concrete bridges up to 320 feet in length and steel bridges up to 120 feet in length. A more in-depth analysis of soil pressure distribution should be made for longer structures.

The abutment need not be designed by the strut and tie model if the longitudinal reinforcement is determined by conventional beam analysis for each of the above cases and a minimum orthogonal grid of reinforcing bars is provided in accordance with Article 5.6.3.6.

Girder End Capacity

The capacity of the end of the girders shall be checked for negative moment using Strength I for steel and concrete girders with an additional check of Service III for prestressed concrete girders. The design load shall be determined by assuming the maximum soil pressure (strength I load factor of 1.00), as determined above, acting on the back of the abutment combined with the lateral pile reaction and moment resulting from thermal expansion (strength I load factor of 0.5). The resulting compression force and bending moment taken about the c.g. of the composite girder section shall be applied to the end of the girders. The loads shall be distributed equally to all girders.

Also, for concrete girders, the tension force resulting from the lateral resistance of the piles due to contraction shall be used in the design of the longitudinal reinforcement of the girders in accordance with Article 5.8.3.5 (strength I load factor of 0.5).

Skew Effects

On structures with skews greater than 25 degrees, the tendency for the structure as a whole to rotate due to the non-concentric soil pressure forces acting against the abutments must be checked. A rotational moment about the center of the structure is induced by the soil pressure (strength I load factor of 1.00) acting on the abutment backwall at an angle normal to the backwall minus the soil-concrete interface friction angle;

$$\delta = \tan^{-1}(0.8 \tan \phi_f) \quad (\text{Article 10.6.3.3})$$

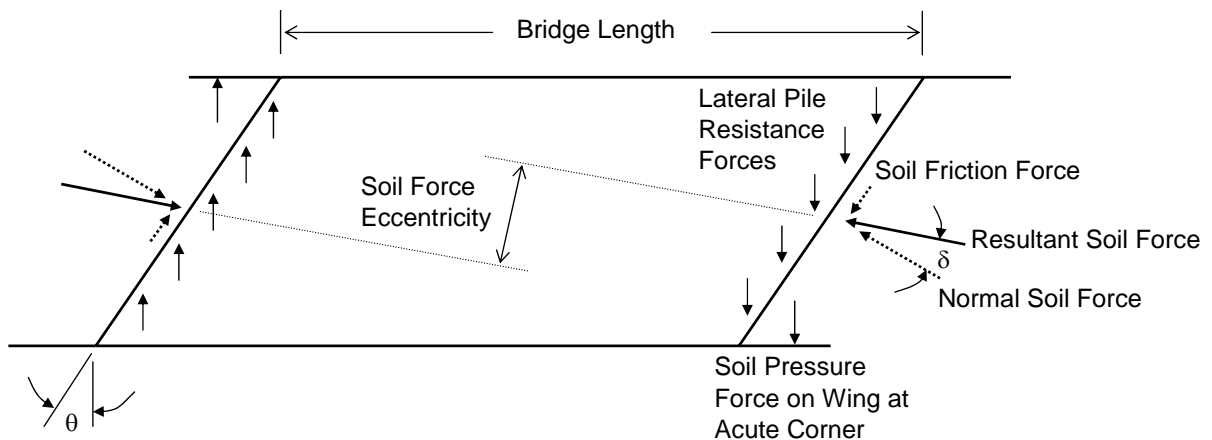
Where: δ = soil-concrete friction angle
 ϕ_f = internal soil friction angle

If δ is greater than or equal to the bridge skew angle there will be no tendency for the structure to rotate and no further check is required. If δ is less than the bridge skew angle the magnitude of the induced rotational moment will be equal to the resultant soil force times the eccentricity of the opposing forces. The resultant soil force is based on the normal soil force (from assumed soil pressure distribution used for the abutment backwall design procedures) increased by the vector addition of the friction component. The eccentricity of these two opposing soil forces is equal to the bridge length times the sine of the difference between the bridge skew angle and the friction angle;

$$M_{RS} = F_{RS}(e_{RS}) \quad F_{RS} = \frac{F_{NS}}{\cos \delta} \quad e_{RS} = L \sin(\theta - \delta)$$

where: M_{RS} = the soil pressure induced rotational moment
 F_{RS} = resultant soil force
 e_{RS} = the eccentricity of the opposing soil forces
 F_{NS} = normal soil force based on the assumed soil pressure distribution
 δ = the soil-concrete friction angle
 L = bridge length
 θ = the bridge skew angle

The resulting rotational moment must be resisted by a combination of the lateral pile resistance (strength I resistance factor of 0.55, ITD policy), and the soil force acting against the inside face of the wings at the acute corners (strength I resistance factor of 0.50, Table 10.5.5-1), as indicated in the sketch below. It can be assumed for simplicity that the resisting forces in the piles as well as the soil force against the wing walls is applied at right angles to the bridge centerline and their respective eccentricities calculated accordingly.



Wing Wall Design

The wing walls shall be designed for at-rest pressure unless they are utilized to resist the rotational tendency of skewed bridges. In which case the wings at the acute corners shall be designed for the actual pressure required to stabilize the structure but need not exceed the passive pressure (strength I factor of 1.35).

Approach Slabs

Approach slabs shall be used on all integral abutment bridges with a total thermal movement of more than $\frac{3}{4}$ inch. This will result in approach slabs on all concrete girder bridges over 130 feet long and on all steel girder bridges over 65 feet long. The expansion joints at the ends of the approach slabs need only be sized to accommodate thermal expansion assuming the joints are constructed at 60° F with a maximum temperature of 80° F for concrete and 100° F for steel.

Commentary

The allowable bridge length for integral abutments was determined by limiting the total thermal movement range to 4", which results in 2" of movement per abutment. Studies at Iowa State University in 1987 and at the University of Tennessee in 1996 have shown that for lateral displacements of H-piles up to 2" there is no reduction in vertical capacity of the pile. Therefore the only design requirements are vertical capacity and ductility, provided the piles remain embedded in the soil. (It is unlikely that a bridge would remain in service with an abutment that has scoured to the extent the piles become exposed for any significant length.) When the bridge is skewed more than 25 degrees there is also the design consideration for lateral capacity if it is assumed that the piles are used to resist skew induced rotation.

It is preferred to orient H-piles so that thermal expansion and contraction causes bending about the strong axis. While the resulting forces induced in the abutment will be higher, the pile itself will handle larger deflections without flange buckling. The forces and moments induced in the pile due to thermal deflections should be determined based on the soil-pile interaction assuming the pile head is fixed against rotation. This can be done using the COM624 program or a similar program that takes into account the soil properties. In order to simplify details and provide sufficient room for reinforcement the piles on skewed bridges should also be skewed so that the flanges remain parallel with the abutments.

Studies by the University of Tennessee in 1999 showed that piles with an embedment depth of 2 feet led to significantly lower stresses in the concrete and, in turn, to significantly less cracking at large values of lateral displacement when compared to piles embedded only 1 foot.

The equations used to determine pile ductility are from, "Rational Design Approach for Integral Abutment Piles," Transportation Research Record 1233 (year 1983).

The assumed soil pressure distribution at the abutments, which is based on passive pressure for the top third of the abutment varying to at-rest pressure at the base, was developed by Maine as the result of studies done in 1992 where the pressure was monitored behind an integral abutment for one year. Because the appropriate maximum span length for this distribution is not known it is limited here to a deflection into the soil of a ¼ inch, assuming the abutments are constructed at 60° F.

The strut and tie model can become complicated for an abutment with a large number of piles and several models may be necessary for the different live load cases. Because the minimum reinforcement requirements of Article 5.6.3.6 almost always governs when checking the strut and tie model it is sufficient to design the main steel for bending using conventional analysis and then provide the orthogonal grid of minimum reinforcement required for strut and tie.

Skew affects do not need to be considered for skews less than 25 degrees. The soil-to-concrete friction angle at the abutment will always be at least 25 degrees; therefore soil friction alone will stabilize the structure. The ultimate lateral capacity of the piles, for the purpose of resisting rotational effects, shall be defined as the lateral force developed in the pile when subjected to a lateral displacement of 2". As stated above this is the limiting displacement for which there is no reduction in vertical capacity of the pile.

Approach slabs are needed to prevent excessive compaction behind the abutments as well as provide an expansion joint that will minimize, if not prevent, the approach pavement from shoving, settling and cracking. It also isolates the joint away from the main structure where damage due to a leaking joint will be minimized. The joint width at the end of the approach slab where it rests on the sleeper beam should only be large enough to prevent the joint from completely closing during hot weather, with an allowance for the minimum compressed width of the joint seal material. It is not necessary to design the joint for the full movement range that would be required in a typical joint design.